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RADIO CORPORATION OF AMERICA
Semiconductor and Materials Division
Somerville, New Jersey

HIGH CAPACITY MAGNESIUM BATTERIES

REPORT NO. 1

SIGNAL CORPS CONTRACT NO.

DA-36-039-sc-85340

DEPARTMENT OF THE ARMY

PROJECT NO. 33-18-03-001-01

FIRST QUARTERLY PROGRESS REPORT

1 JUNE 1960 TO 31 AUGUST 1960

U.S. ARMY SIGNAL RESEARCH

AND DEVELOPMENT LABORATORY

FORT MONMOUTH, NEW JERSEY

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HIGH CAPACITY MAGNESIUM BATTERIES

REPORT NO. 1

SIGNAL CORPS CONTRACT NO. DA-36-039-sc-85340

DEPARTMENT OF THE ARMY PROJECT NO. 3G -18-03-001-01

First Quarterly Progress Report

1 June 1960 to 31 August 1960

The object of this research and development project is the development of high-capacity magnesium primary batteries using the perchlorate electrolyte systems.

This report prepared by

G. S. Lozier
G. S. Lozier

R. G. Ryan
R. G. Ryan

Approved by

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1. PURPOSE

The purposes of this research and development contract are to

1. Develop practical Mg-CuO and Mg-HgO reserve cells suitable for utilization in high-rate batteries.
2. Characterize the $\text{Mg/Mg(ClO}_4)_2/\text{MnO}_2$ and $\text{Mg/Mg(ClO}_4)_2/\text{CuO}$ dry cells.
3. Perform research studies to determine the factors and mechanisms controlling anode efficiency, inhibitor function, and delayed action of the magnesium anode with emphasis on the perchlorate electrolyte.

2. ABSTRACT

This abstract describes briefly the significant accomplishments and progress made on the U. S. Army Signal Research and Development Laboratories Battery Program by the Radio Corporation of America, Semiconductor and Materials Division, during the first quarterly period, from June 1, 1960 to August 31, 1960. The subject matter in this abstract is divided into the major areas of endeavor for convenience of review.

Mg/Mg(ClO₄)₂ CuO reserve cells were characterized on high rates using a cell design previously developed. Several voltage variations, caused by the heat evolved, were noted during discharge.

A research study was initiated to determine the mechanism by which the heat evolved influences the voltage behavior of the system.

Shelf-life programs were initiated to study the delayed action, impedance, and capacity retention characteristics of the Mg/Mg(ClO₄)₂/MnO₂ and Mg/Mg(ClO₄)₂/CuO dry cells. Initial delayed action, impedance and capacity data are presented for the MnO₂ cells.

3. CONFERENCES

On June 22, 1960, Drs. C. K. Morehouse and G. S. Lozier and Mr. R. J. Ryan visited the U. S. Army Signal Research and Development Laboratories at Fort Monmouth, New Jersey, to discuss the overall program and the objectives of the contract. Present at the meeting were Dr. D. Fischbach and Messrs. A. Daniel, F. John, J. Hovendon, D. Wood, H. Knapp, and A. Almerini of the U. S. Army Signal Research and Development Laboratories.

On August 10, 1960, Messrs. J. Hovendon, D. Wood, and A. Almerini of the U. S. Army Signal Research and Development Laboratories visited RCA in Somerville, New Jersey, to discuss progress under the subject contract. Present at the meeting were Dr. G. S. Lozier and Mr. R. J. Ryan of RCA.

4. EXPERIMENTAL AND FACTUAL DATA

4.1 PRIOR WORK ON MAGNESIUM CELLS WITH A MAGNESIUM PERCHLORATE ELECTROLYTE

Prior to this contract, a research program at the RCA Laboratories demonstrated the advantages of a perchlorate electrolyte in magnesium primary cells. Some of the important properties of the perchlorate electrolyte are:

- a. It is less corrosive to a magnesium anode than either a magnesium chloride or a magnesium bromide electrolyte. At high-current drains, magnesium operates at an anode efficiency of 80 percent. This feature reduces the amount of water required for cell reaction and the amount of $Mg(OH)_2$ formed. These properties are desirable for the efficient design of magnesium batteries.
- b. Magnesium has a low level of static corrosion in a perchlorate electrolyte, thereby insuring a good shelf life for dry cells or an extremely long activated stand capability for reserve cells.
- c. The perchlorate electrolyte does not react with cupric oxide, mercuric oxide, silver II oxide, or nickel dioxide, thereby permitting the coupling of these high-capacity cathode materials to a magnesium anode. These are the most desirable cathode materials for the design of batteries with a high capacity at high discharge rates.

The performance characteristics of the magnesium-magnesium perchlorate cells are presented in Figures 1, 2, 3, 4, and 5. Presented in Figures 1 and 2 are watt-hour capacity data per unit of weight and volume obtained from single cells.

As evidenced by the data presented in Figure 3 and in Table 1, satisfactory shelf-life data have been obtained from cells made with cupric oxide and synthetic manganese dioxide.

The impedance of $\text{Mg}/\text{Mg}(\text{ClO}_4)_2/\text{MnO}_2$ (Afr.) AA-size cells has been shown to be similar to that of comparable $\text{Mg}/\text{MgBr}_2/\text{MnO}_2$ (Afr.) AA-size cells. Data for the impedance of $\text{Mg}/\text{Mg}(\text{ClO}_4)_2/\text{MnO}_2$ (Afr.), $\text{Mg}/\text{MgBr}_2/\text{MnO}_2$ (Afr.), and commercial LeClanche cells as a function of load resistance are presented in Figure 4.

The delayed action of magnesium cells containing a magnesium perchlorate electrolyte in preliminary studies has been shown to be less than that of similar cells containing a magnesium bromide electrolyte. This is particularly true for applications in which the time between discharges is short as evidenced by the delayed action data for D-size cells on a test simulating the BA-30 test presented in Figure 5.

4.2 RESERVE CELLS

4.2.1 Introduction

The magnesium-cupric oxide system was selected for the development of a high-capacity reserve battery for the following reasons:

- a. High capacity per unit weight and volume
- b. Flat discharge curve
- c. Potential low cost

4.2.2 Magnesium-Cupric Oxide Reserve Cell Design

A 3-ampere hour cell was selected for initial study and characterization because this size cell is readily adapted to laboratory development and comparison to other systems.

- 4.2.2.1 The cathode plates were constructed using techniques previously developed in this laboratory. The following steps are used in the assembly of a cupric oxide cathode:
- a. Dry blend cupric oxide with Shawinigan Acetylene Black using standard techniques.
 - b. Prepare a wet mix using a water solution of HV CMC (carboxymethyl cellulose) with suitable wetness to provide maximum ease of handling in steps c and d.
 - c. Paste a weighed amount of cathode mix on the metal grid.
 - d. Apply the separator material to the wet cathode plate and press to a pressure of 3,000 to 5,000 psi for several seconds.
 - e. Air dry overnight.

4.2.2.2 In the following studies, the anode and cathode specifications are:

a. Cathode:

Size - 2 x 2 inches

Grid - 25/0.010-inch woven bronze screen 0.575 g/in²
with a 1/2 x 3/4-inch tab for making connections.

Wet mix composition - 42.8% CuO

10.7% Shawinigan Acetylene Black

45.7% H₂O

.7% HV CMC

Separator - analytical grade filter paper

Theoretical capacity per plate - 85 ampere minutes.

b. Anode:

Size - 2 x 2 inches with 1/2 x 3/4-inch tab for making connections.

Weight - 0.005-inch plate 0.74 g

 0.010-inch plate 1.06 g

 0.014-inch plate 1.73 g

Theoretical capacity per plate (not including tab)

 0.005-inch 76.7 amp minutes

 0.010-inch 151 amp minutes

 0.014-inch 200 amp minutes

c. Cell Assembly:

The cells were assembled by soldering four cathode plates together and interweaving 5 magnesium anode plates between the cathode plates. The tabs of anode plates were spotwelded together and connected to a copper wire lead.

4.2.3 Cell Characterization

4.2.3.1 Effect of Discharge Rate

The discharge characteristics of 3 ampere hour Mg-CuO cells determined under constant current drains of 10 to 25 amperes are presented below and in Figures 6, 7, and 8.

<u>Amperes</u>	<u>Magnesium Anode</u>	<u>Discharge Time (minutes)</u>	<u>Average Voltage</u>	<u>Cathode Efficiency (%)</u>
10.0	0.014-inch comm pure	30	0.835	88
20.0	0.014-inch comm pure	13	0.82	76½
25.4	0.005-inch comm pure	6.5	0.715	49
20.0	0.016-inch AZ-31B	9.4	0.68	55

The cells were placed in a plastic test container to restrict volume and were discharged in excess 2 N $\text{Mg}(\text{ClO}_4)_2$ five minutes after activation.

All cells showed a voltage rise during discharge which was greatest at the lighter drains as evidenced by the 10 ampere discharge data in Figure 8. The voltage changes that occur during discharge are believed to be due mainly to the heat evolved by the cell reactions. The effect of temperature on cell design, component composition and physical properties will be investigated in order to improve performance.

4.2.3.2 Effect of Cupric Oxide to Carbon Ratio on Cell Performance

The effects of the CuO to carbon ratio on the cathode efficiency and the voltage-time characteristic were determined on cells with a theoretical capacity of 300 to 340 ampere minutes on a 20 ampere drain. In these cells, the number of plates in the cathode was varied to keep the theoretical capacity approximately constant. The composition of the cells is presented in Table 2. The cathode efficiency increases as the active material ratio is decreased and as the plate surface area is increased as shown in Figure 9 and Table 2.

As would be expected if the voltage rise is due to the heat evolved, the CuO to carbon ratio had little effect on the percentage voltage increase.

4.2.4 Research Studies

A research study was initiated to determine the mechanism by which the heat evolved influences the voltage behavior of the magnesium-cupric oxide reserve cell system. The temperature rise found on cell discharge is due to the heat evolved by the corrosion reaction and the irreversibility of the magnesium anode. Since both of these factors are dependent on the current density, the temperature rise will be greatest on high discharge rates.

Test cells were made using two cupric oxide plates of 3 to 1 ratio to Shawinigan Acetylene Black and 3 anode plates of various magnesium alloys. The cupric oxide plates were taken from the lot whose test results are shown in Figure 9 with a theoretical capacity of 60 ampere minutes per plate. AZ-31B, AZ-21, AZ-10, and commercial pure magnesium anodes were used in these studies. The cupric oxide cathode plates were discharged for 16 hours on an 80-hour rate for stabilization prior to the assembly of the test cells. A silver-silver chloride reference electrode was included at the end of each cell for half-cell measurements. The cells were placed in beakers with excess 2N $\text{Mg}(\text{ClO}_4)_2$, immersed in constant-temperature water and discharged through a 32-ohm resistor, corresponding to a 50-hour rate. The cell, anode-to-reference and cathode-to-reference potentials were measured over a temperature range of 2°C to 70°C.

The results of this study are presented in Figures 10 and 11. It is seen that the voltage increased linearly with temperature except for

the range between 350C and 500C. The half-cell measurements show that the marked increase in cell voltage in this temperature range is due to the cupric oxide cathode. The factors causing this rise are unknown at the present time.

A voltage difference of 0.2 volt was found between the AZ-31 and pure magnesium anodes. This difference increased at higher temperatures because the corrosion reaction for pure magnesium was greatly accelerated. The effect of corrosion reaction on cell discharge voltage can be seen from the data in Figure 6.

This study will be continued and will include anode efficiency measurements at various current drains. Further efforts will be made to determine the mechanism of voltage fluctuation.

4.3 DRY CELLS

A program has been initiated to determine the shelf life of $\text{Mg}/\text{Mg}(\text{ClO}_4)_2/\text{MnO}_2$ and $\text{Mg}/\text{Mg}(\text{ClO}_4)_2/\text{CuO}$ dry cells. The program will include a study of capacity, delayed action, and impedance as functions of storage time.

4.3.1 Cell Formulation

The $\text{Mg}/\text{Mg}(\text{ClO}_4)_2/\text{MnO}_2$ (Type M) cell formulation for these studies is:

<u>Material</u>	<u>% (by weight)</u>
MnO_2 (Type M)	84.5
Shawinigan Acetylene Black	9.7
BaCrO_4	2.9
$\text{Mg}(\text{CH})_2$	2.9

Wetness - milliliters/1000 g dry mix.

507 ml. 2N $\text{Mg}(\text{ClO}_4)_2$
with 1 g/l Li_2CrO_4
and 1/2 g/l $\text{Mg}(\text{OH})_2$

Bobbin - 7 g wet mix/AA cell.

The cells were aged two weeks before the initial data were taken.

4.3.2 Delayed Action Shelf Study

The delayed action program was set up to determine cell voltage delay and capacity on a radio transceiver drain. The AN/PRC-35 (XC-2) under development A_2 unit drain was selected for testing as this represents a more severe change from low to high current than most transceiver applications. The requirements for the A_2 unit are 8 ma for 18 minutes and 138 ma for 2 minutes.

Figure 12 gives a typical discharge curve for the initial capacity of a $\text{Mg}/\text{Mg}(\text{ClO}_4)_2/\text{MnO}_2$ (Type M) AA cell for the above drain. The data are plotted as continuous for the 2-minute and 18-minute cycles.

The delayed-action data for this cell are presented in Figure 13 for the initial 2-minute cycles and at various points during the cell discharge. The delayed action for the initial 2-minute cycle is much greater than for the succeeding cycles and can be attributed to the chromate film obtained in the can pickling process and the concentration of lithium chromate added to the electrolyte. This delay diminishes quickly with subsequent cycling to a relatively constant value of less than one fifth of a second.

Further studies will include comparison with cells using AZ-31 magnesium anodes and cells with MgBr_2 electrolyte.

4.3.3 Impedance Studies

Cell impedance is an important factor effecting the performance of equipment in many electronic applications. Previous data have shown the impedance of magnesium cells to be greater than that of corresponding LeClanché cells.

The present study will include an intensive investigation of the impedance of $\text{Mg/Mg}(\text{ClO}_4)_2/\text{MnO}_2$ and $\text{Mg/Mg}(\text{ClO}_4)_2/\text{CuO}$ cells as a function of shelf-life for various frequencies and load conditions.

The experimental apparatus is shown in Figure 14. At each frequency, the voltage drop across fixed resistor R is measured at V_x and V_y .

Then, by Ohm's Law, the ac current flowing through the battery is

$$I = \frac{V_x}{R+R_b} = \frac{V_y}{R_b}$$

where R_b is the battery impedance. By making $R \gg R_b$, the following approximation can be made:

$$R_b = \frac{V_y}{V_x} R$$

For convenience of calculation, R was set at 1000 ohms and V_x at 1.00 volt by the amplitude control of the audio oscillator.

The variation in impedance is presented in Figure 15 at 60 and 400 cps as a function of load resistance for AA-size $\text{Mg/Mg}(\text{ClO}_4)_2/\text{MnO}_2$ (Type M) cells. Figure 16 gives the variation in impedance with

frequency for the various discharges. The data represent initial 2-week-old-cell impedance measured at approximately 50 per cent discharge to a 0.90-volt cut off.

Cell capacity data for the various drains are given in Table 3. The impedance study at several drains will be continued on cells stored at 70°F and 113°F.

4.3.4 Capacity

Shelf-life data, presented in Table 1 and Figure 3, have shown that good capacity retention is obtained with $\text{Mg/Mg(ClO}_4)_2/\text{MnO}_2$ cells and $\text{Mg/Mg(ClO}_4)_2/\text{CuO}$ cells. These data will be extended to provide a larger sample using A-size MnO_2 and CuO cells stored at 70°F and 113°F.

5. CONCLUSIONS

The cathode efficiency of $\text{Mg}/\text{Mg}(\text{ClO}_4)_2/\text{CuO}$ reserve cells varied from approximately 50 per cent on a 6-minute-discharge rate to over 75 per cent on a 30-minute-discharge rate.

Several voltage variations, caused by the heat evolved, were noted during discharge. In the temperature range of 35°C to 50°C the marked voltage rise is due to the cupric oxide electrode. Above 50°C , the magnesium alloy composition also is a contributing factor in the increased cell voltage.

The delay of fresh cells on a 2- and 18-minute transceiver-type drain was less than one-fifth second throughout the discharge following the initial cycle.

The initial $\text{Mg}/\text{Mg}(\text{ClO}_4)_2/\text{MnO}_2$ (Type M) cell impedance data were in agreement with previous data.

6. PROGRAM FOR THE NEXT QUARTER

1. Research will be continued on $\text{Mg}/\text{Mg}(\text{ClO}_4)_2/\text{CuO}$ reserve-cell discharge characteristics to improve behavior.
2. Reserve cell design and construction will be investigated.
3. Anode efficiency will be measured as a function of temperature.
4. The delayed action and impedance shelf-life programs for $\text{Mg}/\text{Mg}(\text{ClO}_4)_2/\text{MnO}_2$ and $\text{Mg}/\text{Mg}(\text{ClO}_4)_2/\text{CuO}$ cells will be continued. Comparisons will be made with cells using MgBr_2 electrolyte and cells with AZ-31 Mg alloy.

7. KEY PERSONNEL

7.1 IDENTIFICATION

Dr. G. S. Lozier, Project Director, Battery Research and Development

Dr. Lozier received the B.S. degree in chemistry in June, 1952, the M.S. degree in chemistry in June, 1953, and the PH.D. degree in February, 1956, from Western Reserve University, Cleveland, Ohio. From September, 1950 until September, 1953, Dr. Lozier held a Teaching Fellowship at Western Reserve. He received the Electrochemistry Society's Cleveland Section Award as the most outstanding student in electrochemistry.

From September, 1952, to December 1954, Dr. Lozier participated in the Office of Naval Reserve project at the Ultrasonic and Electrochemistry Research Laboratory of Western Reserve University on the investigation of ultrasonic effects on electrode processes. He joined RCA in January, 1955 and did electrochemical research and development work at the David Sarnoff Laboratories, where he received the RCA Achievement Award in 1957.

Dr. Lozier has published a number of technical papers, including two presented before the Electrochemistry Society. A paper has been published recently on fuel cells. Dr. Lozier holds one U.S. patent.

Mr. R. J. Ryan, Physical Chemist, Battery and Component Development

Mr. Ryan received the B.A. degree, with a major in chemistry, from LaSalle College, Philadelphia, Pennsylvania in 1952. From June, 1952 until September, 1956, Mr. Ryan was employed by the Electric Storage Battery Company in Philadelphia as a development engineer in lead-acid and

nickel-cadmium storage-battery systems and processes. From September, 1956 until March, 1957, Mr. Ryan was in charge of design and development of nickel-cadmium batteries.

He joined the chemical and physical laboratory group at RCA, Camden, N. J. in March, 1957, where he worked on N-halogen organic compounds for use as cathode materials in reserve batteries. At the present time Mr. Ryan is working on electrochemical problems at the Semiconductor and Materials Division in Somerville, N. J. and is completing work toward an M.S. degree in physical chemistry.

D. Hurd, Technician,

From June, 1954 to June, 1956, Mr. Hurd worked at Rohm and Haas Company, Philadelphia, Pennsylvania, as a development laboratory assistant in the Plastics and Resins Division. He was a laboratory technician for the Wilson-Martin Company from June, 1956 to September, 1957, in the Research and Development Laboratory of the Fatty Acid Division. From September, 1957 to March 1959, he was a senior laboratory technician for United Engineers and Constructors Inc., working on low temperature and fluidization of bituminous products.

Mr. Hurd joined RCA, Semiconductor and Materials Division in April, 1959 and has worked on development of primary battery systems and components.

A. Lindabery, Technician

Studied chemistry for 2-1/2 years at Pennsylvania State University after which he spent two years in the U.S. Army. Mr. Lindabery joined RCA in April of 1959. He has had two years experience with magnesium primary cells

since joining R.C.A.

E. Uhler, Technician

Before entering the U.S. Army in 1957, Mr. Uhler studied chemistry at Virginia Military Institute for three years. He will be awarded a B.S. degree in chemical engineering this year from Rutgers University, New Brunswick, N. J. While in the Army, Mr. Uhler spent two years as an assistant project engineer at the Signal Research and Development Laboratory at Fort Monmouth, N. J.

Mr. Uhler has worked closely with various advanced development engineering groups in the improvement and application of materials for use in power sources. Since joining the Microelectronics Department at RCA, Somerville, in September, 1959, Mr. Uhler has been engaged in development work on primary cells, including magnesium dry cells and water-activated cells.

7.2 DISTRIBUTION OF HOURS

G. S. Lozier, Project Director	30 hours
R. J. Ryan, Physical Chemist	301 hours
D. J. Hurd, Technician	287.5 hours
A. Lindabery, Technician	36 hours
E. Uhler, Technician	104 hours

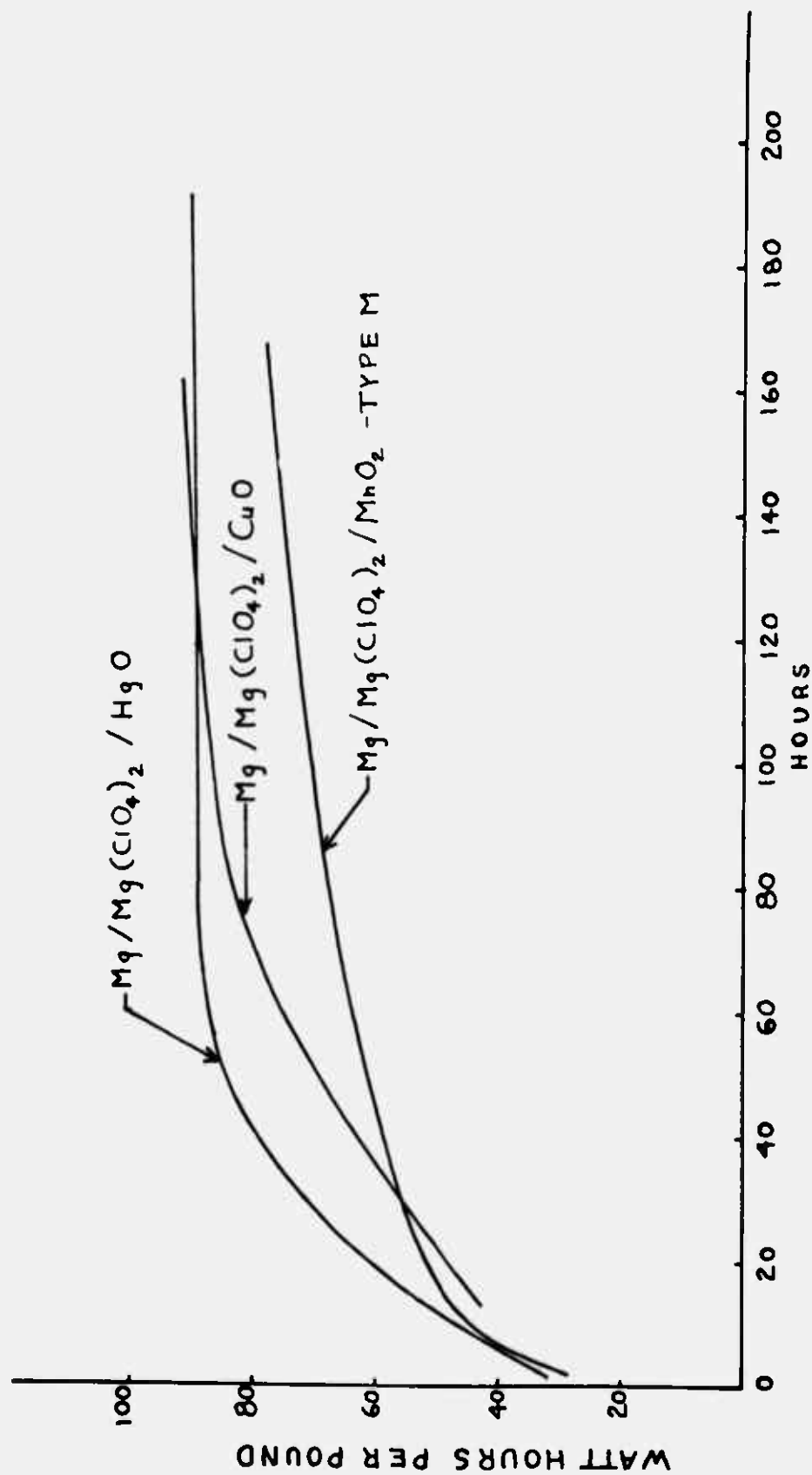


FIGURE 1. WATT HOUR CAPACITY OF VARIOUS DRY CELLS AS A FUNCTION OF DISCHARGE TIME

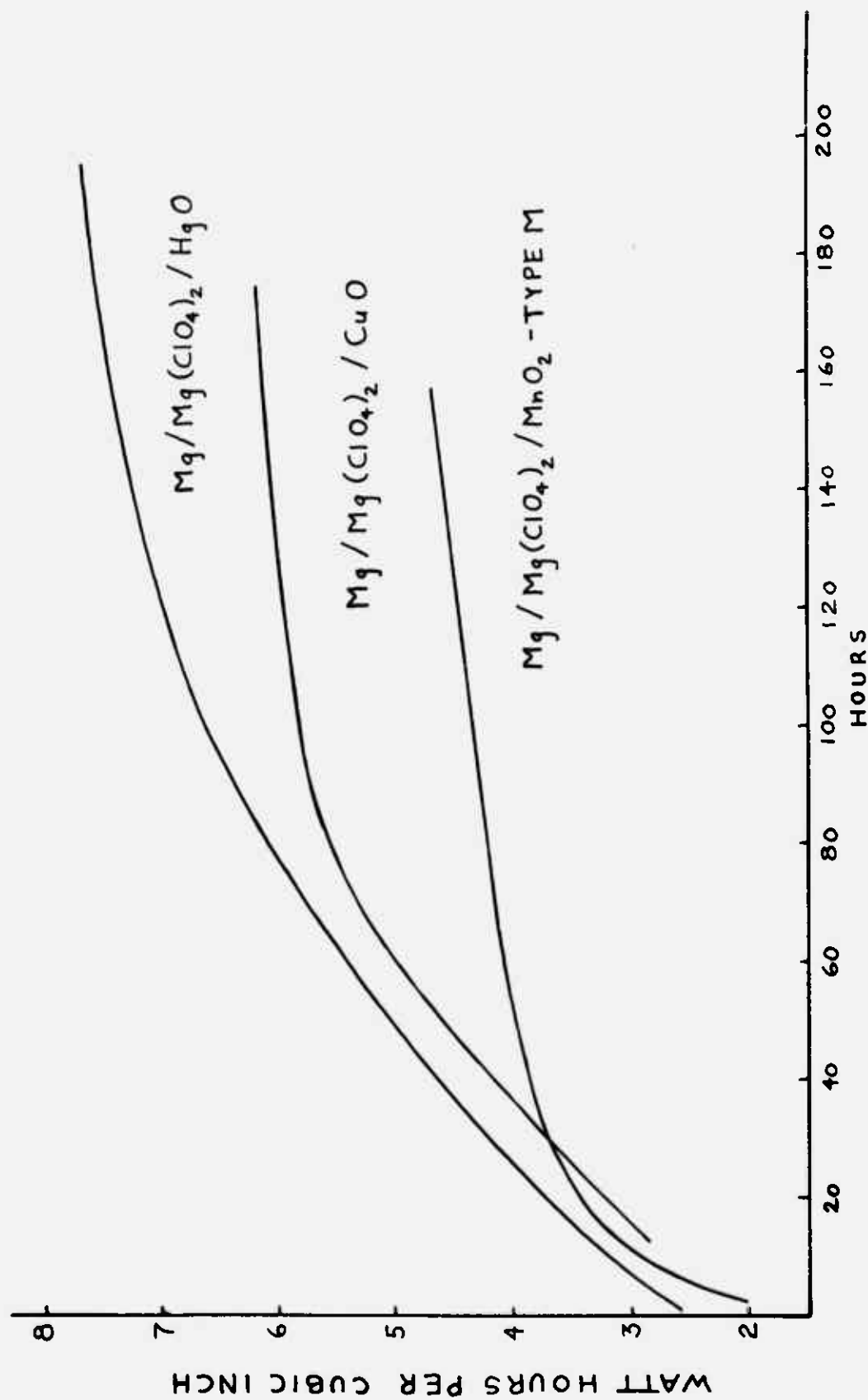


FIGURE 2. WATT HOUR CAPACITY OF VARIOUS DRY CELLS AS A FUNCTION OF DISCHARGE TIME

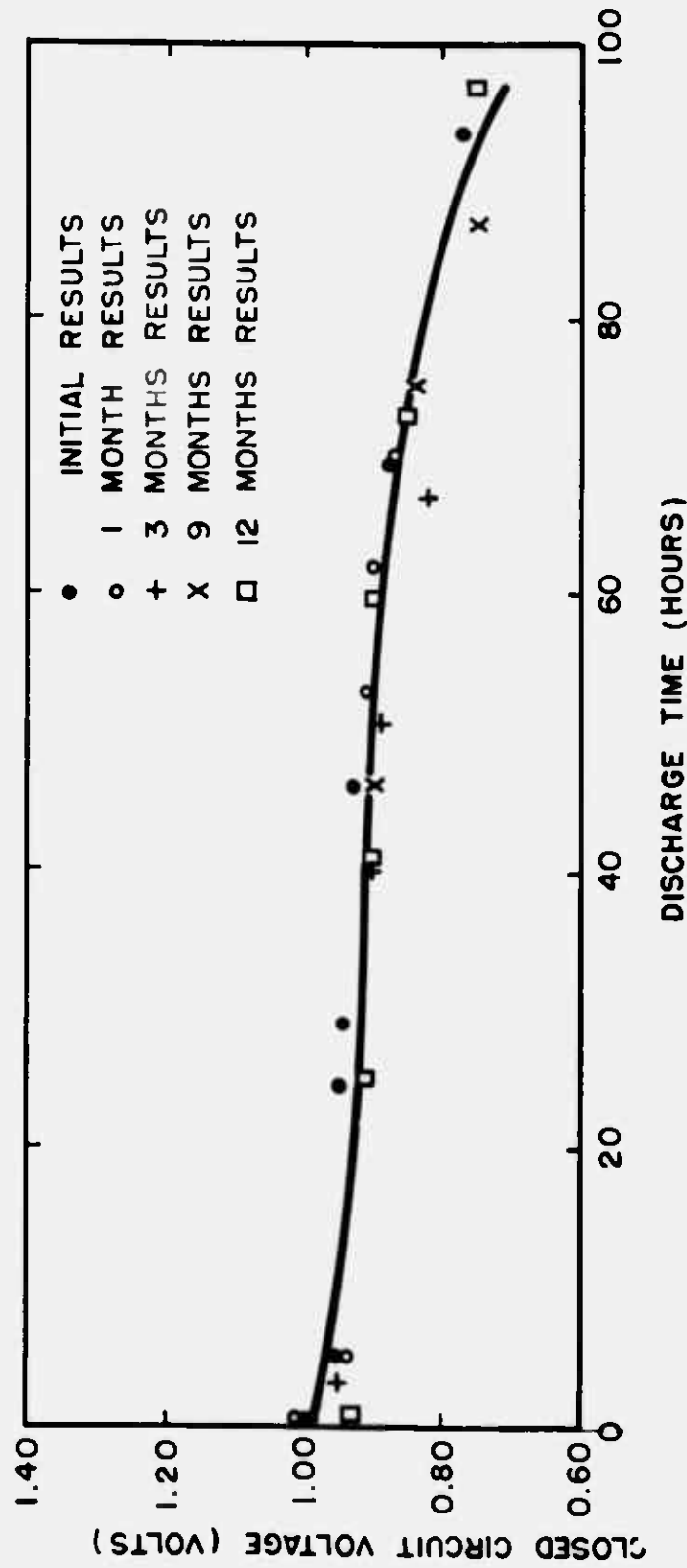


FIG.3. CAPACITY RETENTION OF MAGNESIUM-CUPRIC OXIDE AA-SIZE DRY CELLS STORED AT $70 \pm 2^\circ\text{F}$. AND $50 \pm 5\%$ R.H. (CELLS DISCHARGED CONTINUOUSLY THROUGH A 50-OHM RESISTANCE AT $70 \pm 2^\circ\text{F}$. AND $50 \pm 5\%$ R.H.)

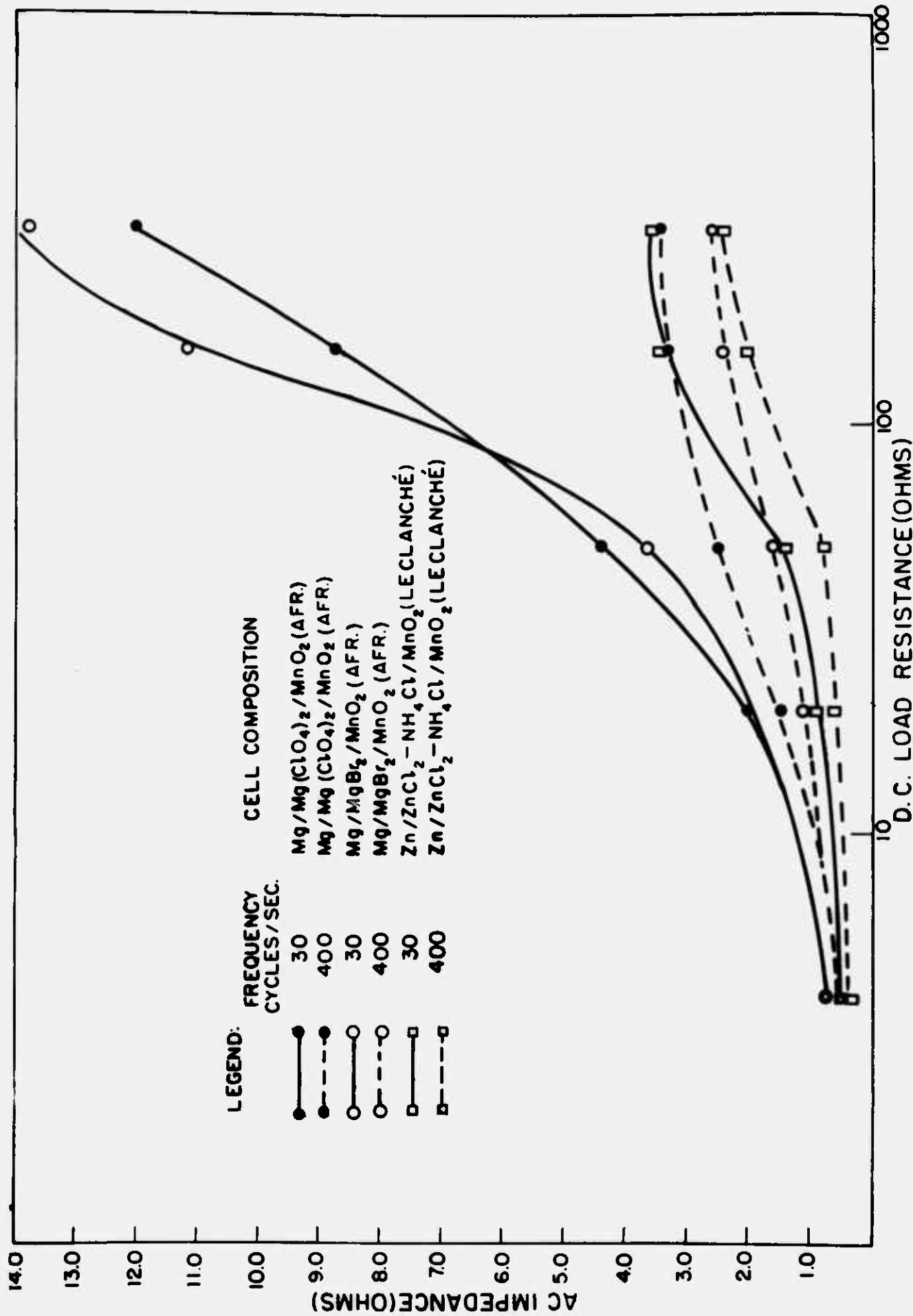


FIG. 4 AC IMPEDANCE vs. LOAD RESISTANCE OF AA-SIZE CELLS DISCHARGED CONTINUOUSLY THROUGH VARIOUS LOAD RESISTANCES AT $70 \pm 2^\circ\text{F}$. AND $50 \pm 5\%$ R.H. (IMPEDANCE MEASURED AT APPROXIMATELY 50% DISCHARGE)

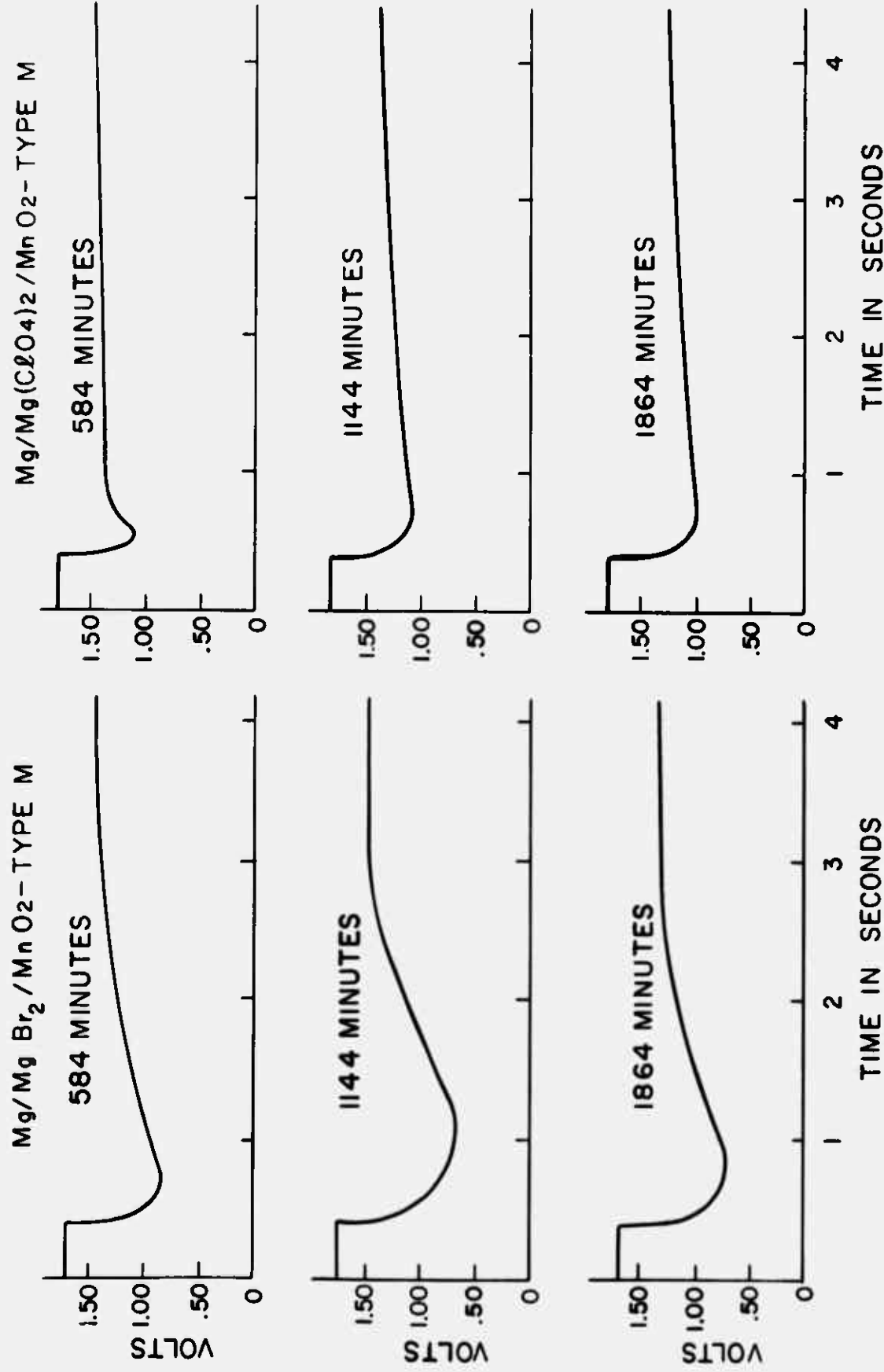


FIG. 5 DELAYED ACTION OF D CELLS DISCHARGED THROUGH 6.6 OHMS
4 MIN/ 1/2 HOUR - 24 HOURS/DAY.

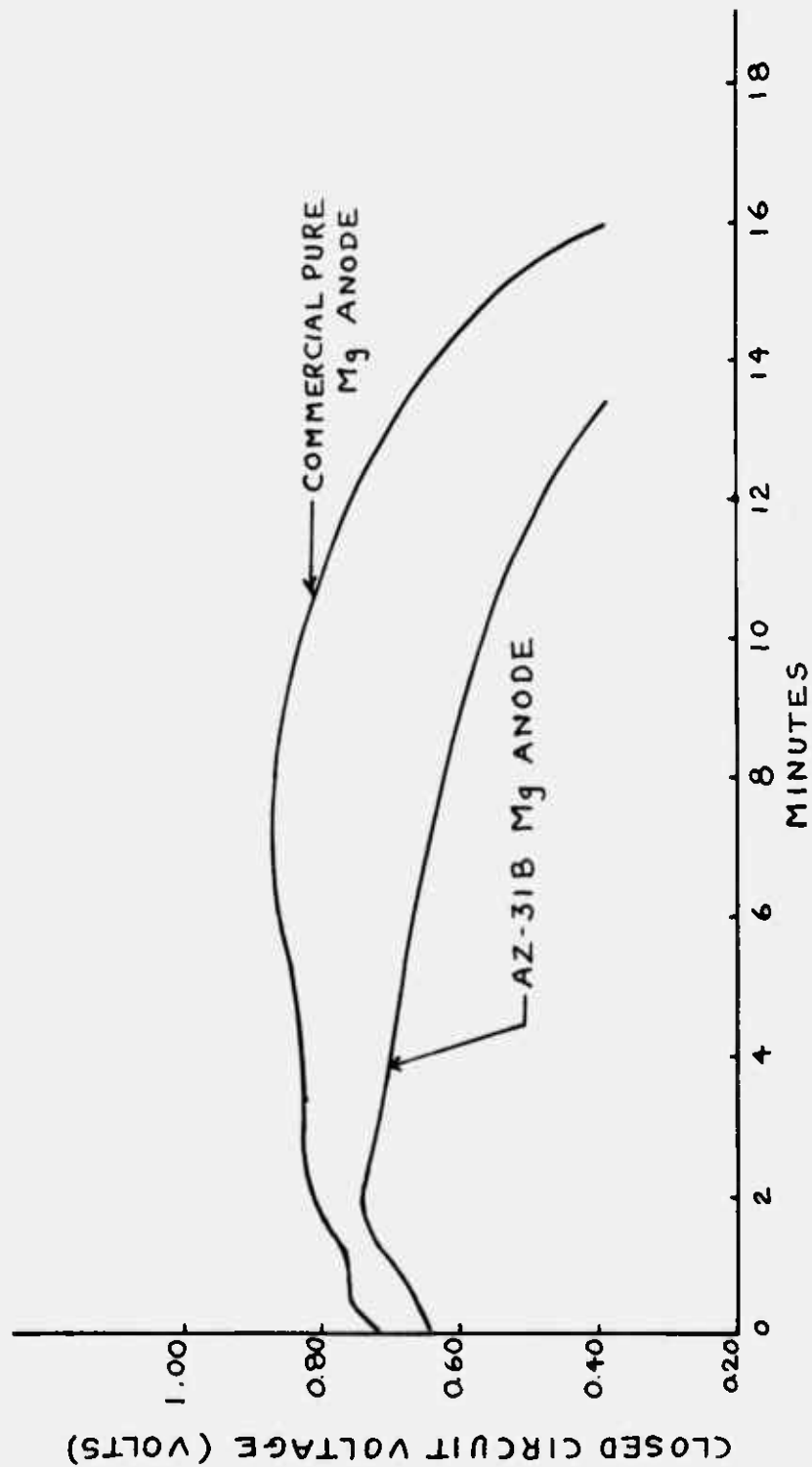


FIGURE 6. CAPACITY DATA FOR Mg/CuO RESERVE CELLS
DISCHARGED UNDER A CONSTANT CURRENT OF
20.0 AMPERES IN $2N Mg(ClO_4)_2$ ELECTROLYTE

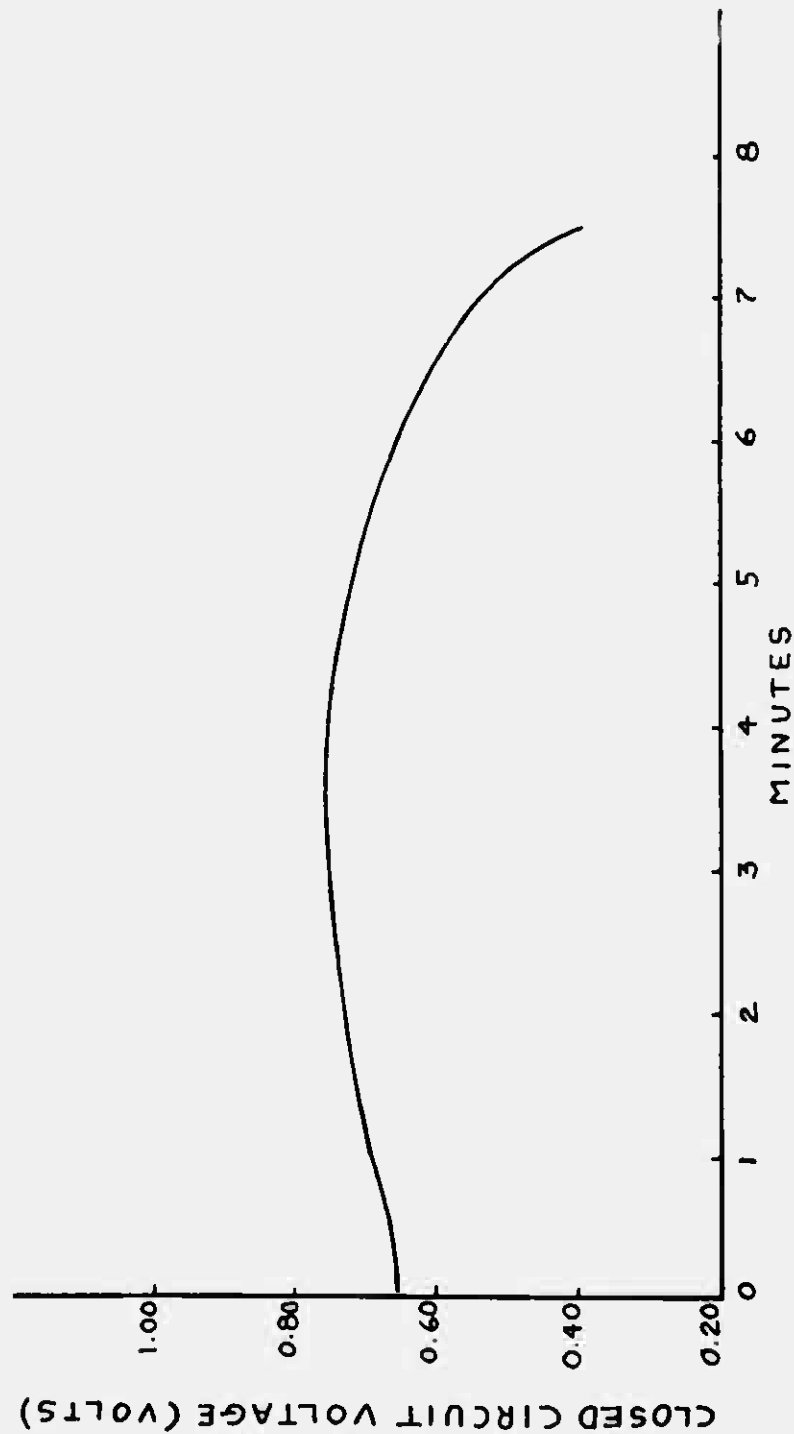


FIGURE 7. CAPACITY DATA FOR Mg/CuO RESERVE CELL
UNDER A CONSTANT CURRENT DRAIN OF 25.4
AMPERES IN 2 N $\text{Mg}(\text{ClO}_4)_2$ ELECTROLYTE

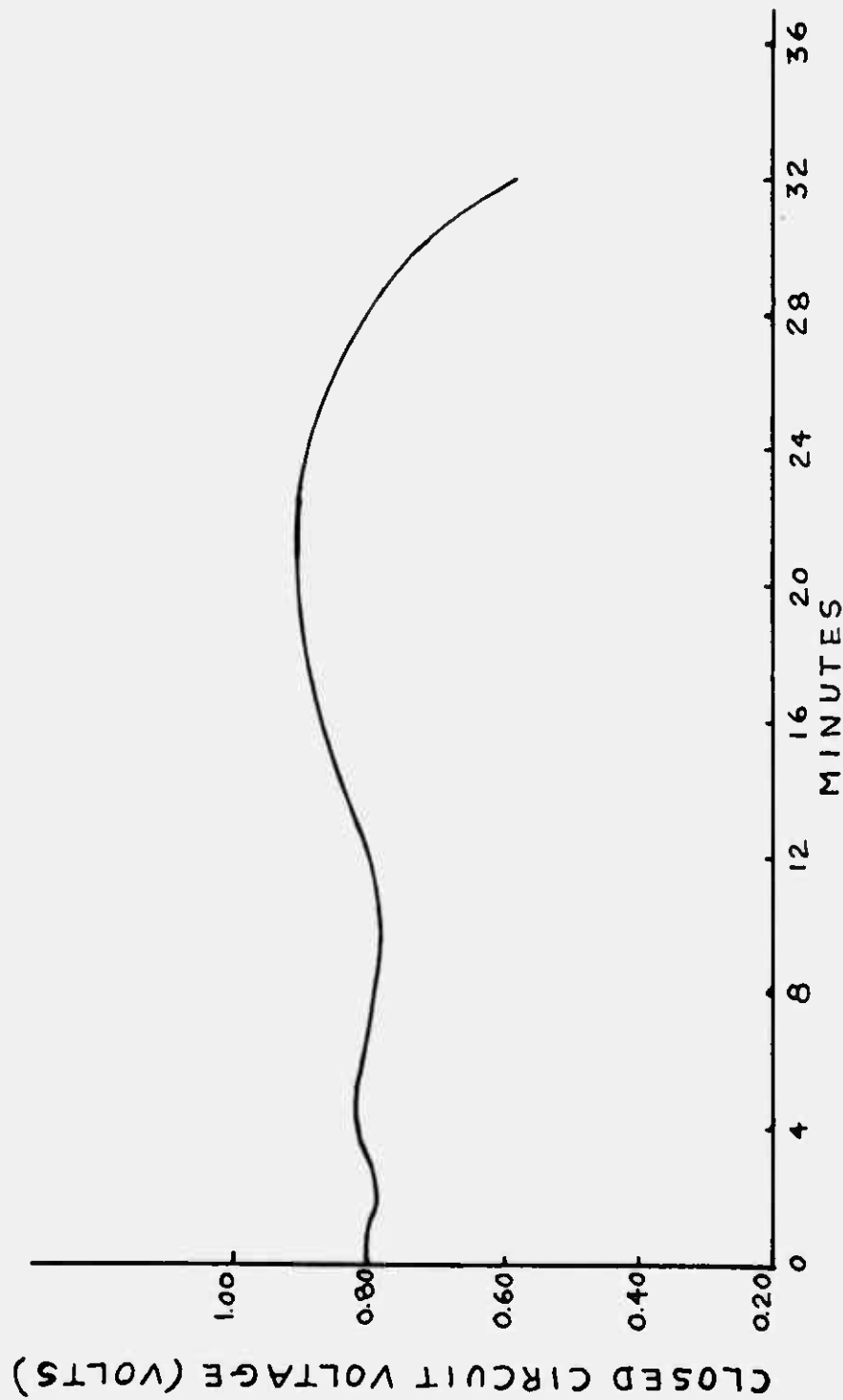


FIGURE 8. CAPACITY DATA FOR Mg/CuO RESERVE CELL
UNDER A CONSTANT CURRENT DRAIN OF
10.0 AMPERES IN 2N $Mg(ClO_4)_2$ ELECTROLYTE

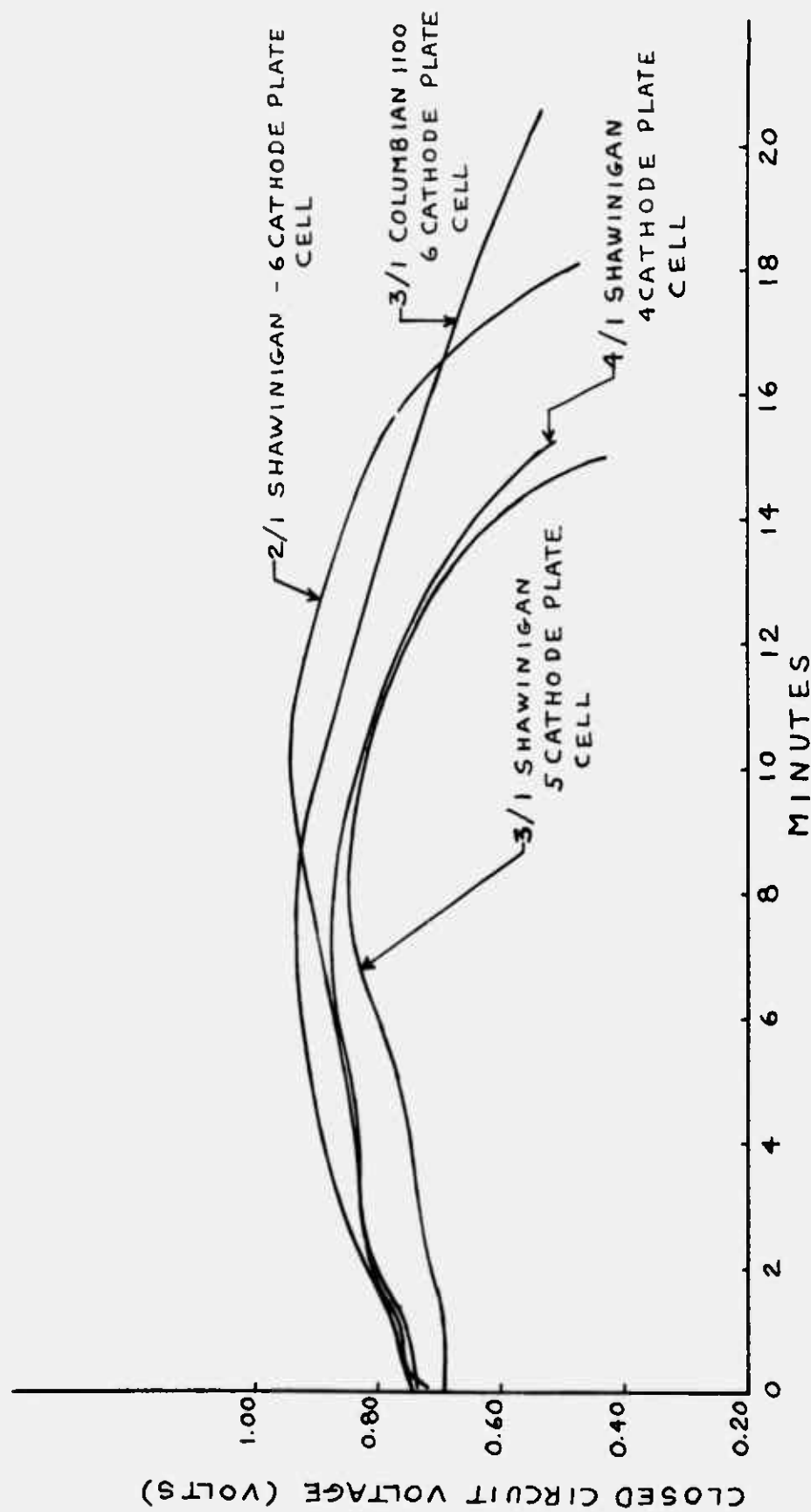


FIGURE 9. CAPACITY DATA FOR Mg/CuO RESERVE CELLS WITH
 VARIOUS CARBON RATIOS UNDER A CONSTANT CURRENT
 DRAIN OF 20.0 AMPERES IN 2N $Mg(ClO_4)_2$ ELECTROLYTE

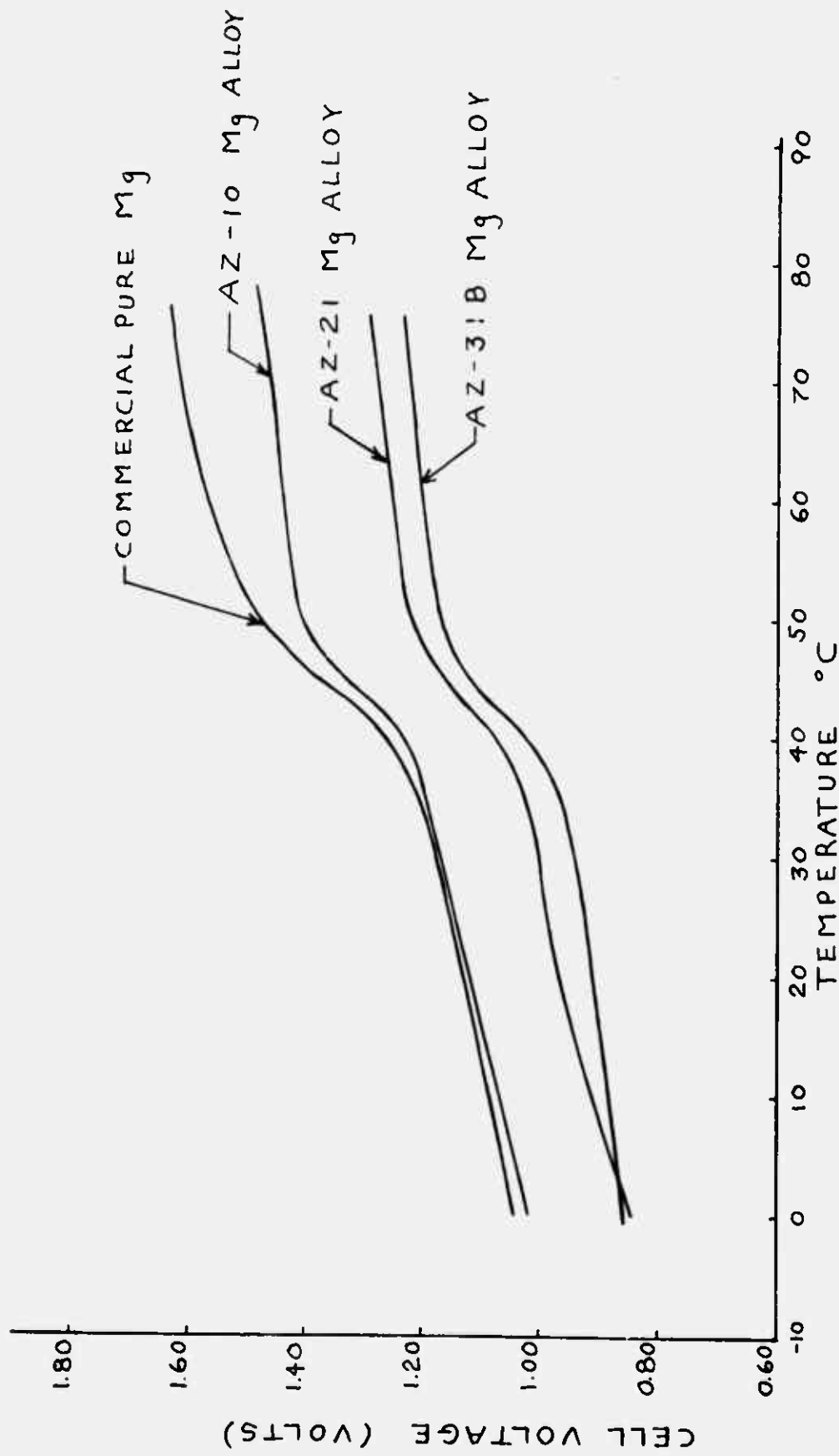


FIGURE 10. EFFECT OF TEMPERATURE ON Mg/CuO RESERVE CELLS
WITH VARIOUS MAGNESIUM ANODES DISCHARGED UNDER
A 50 HOUR RATE IN 2 N $\text{Mg}(\text{ClO}_4)_2$ ELECTROLYTE

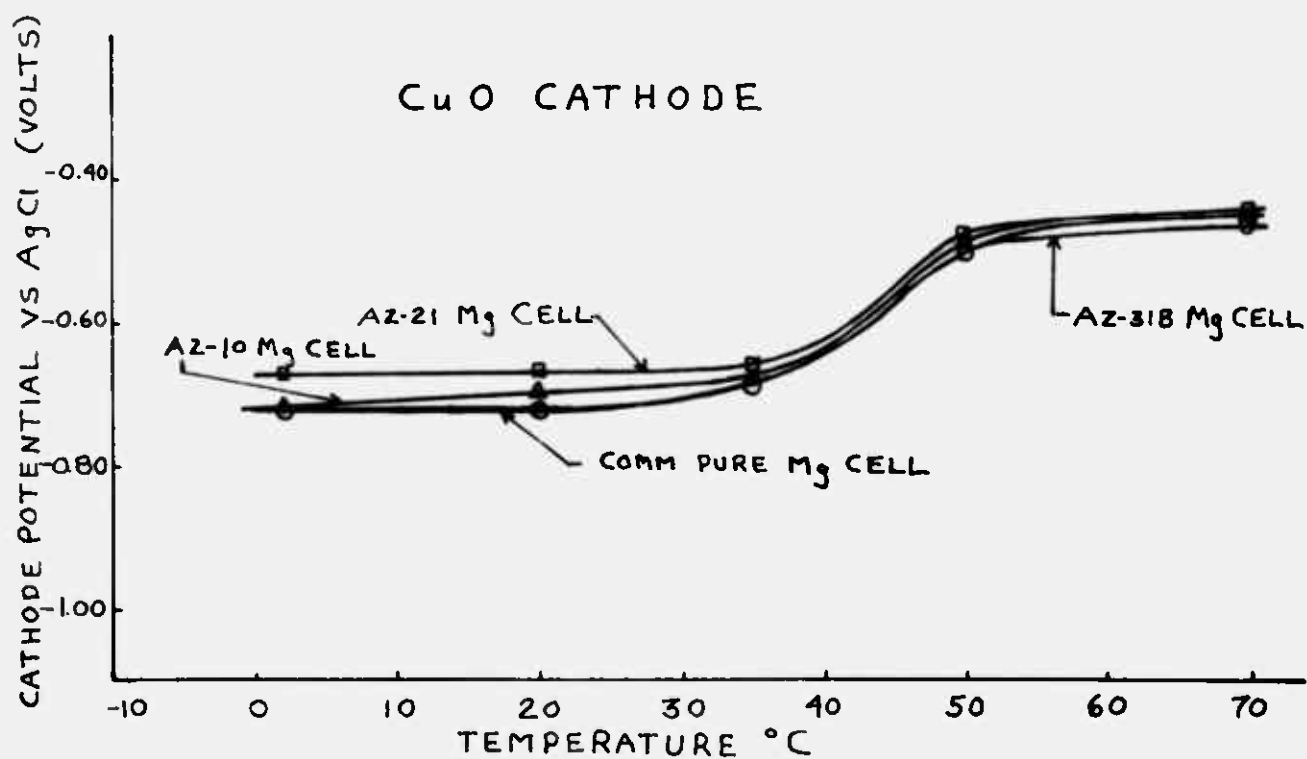
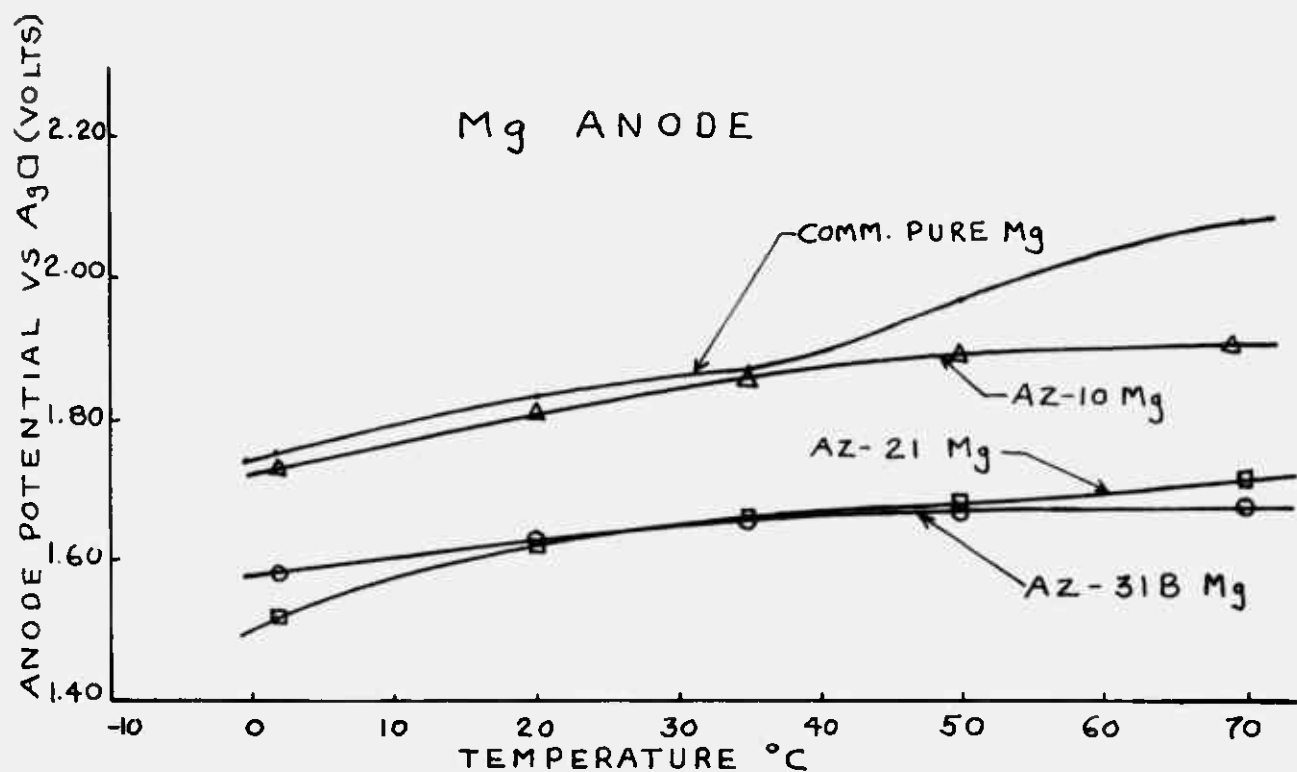


FIGURE II. TEMPERATURE DEPENDENCE OF THE Mg ANODE AND CuO CATHODE IN A Mg/CuO RESERVE CELL IN 2 N $\text{Mg}(\text{ClO}_4)_2$ ELECTROLYTE

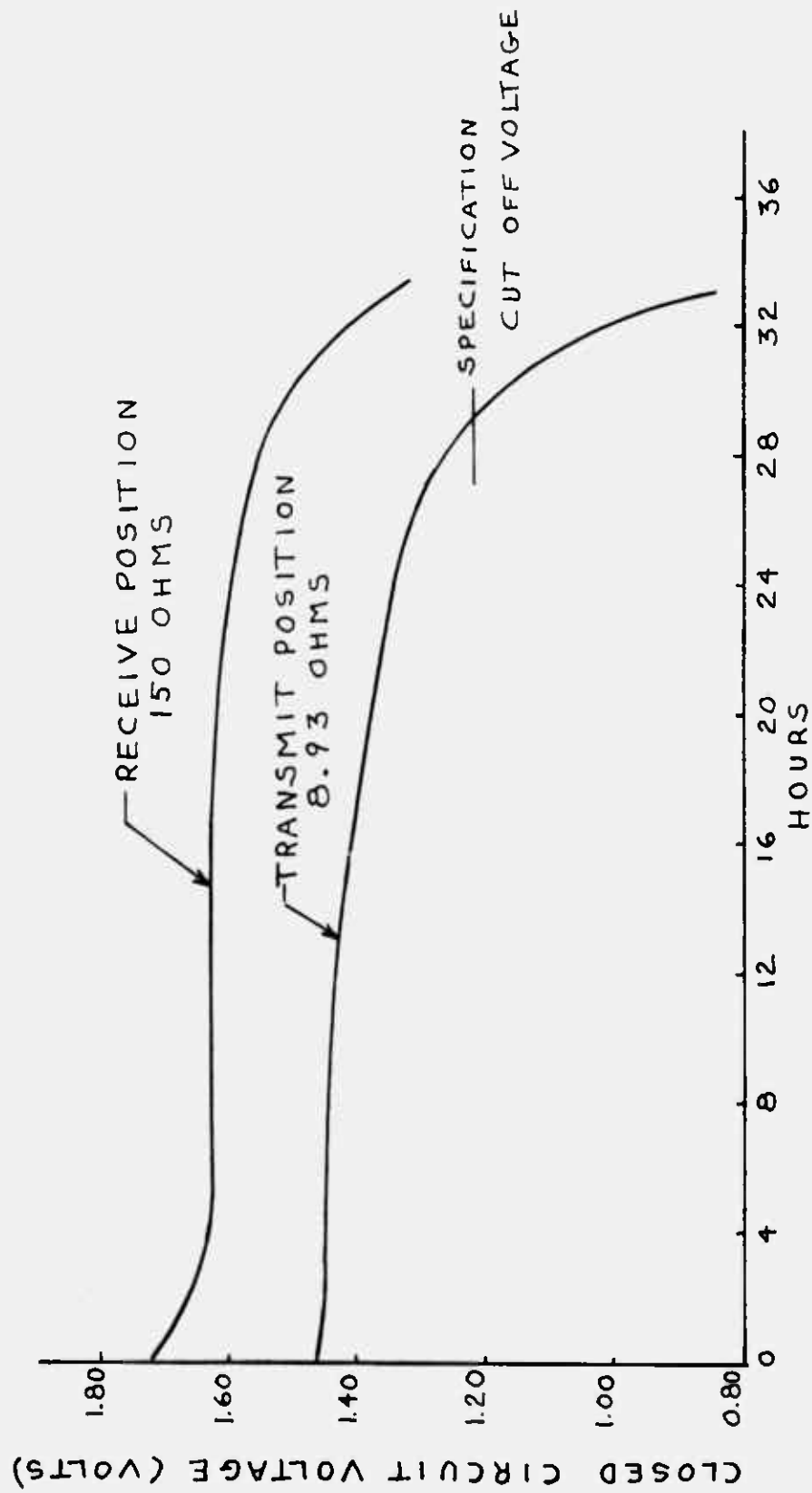


FIGURE 12. CAPACITY DATA FOR $\text{Mg}/\text{Mg}(\text{ClO}_4)_2/\text{MnO}_2$ (TYPE M)

AA SIZE CELLS DISCHARGED INTERMITTENTLY THROUGH
150 OHMS FOR 18 MINUTES AND 8.93 OHMS FOR 2 MINUTES

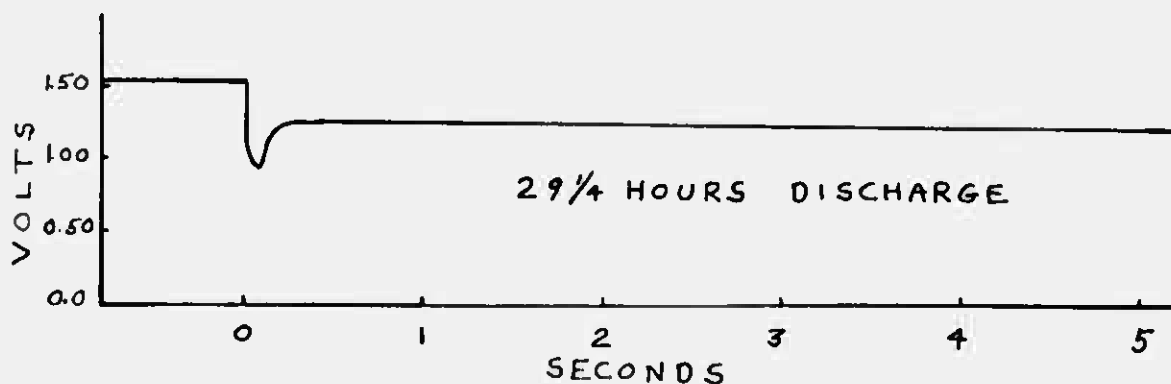
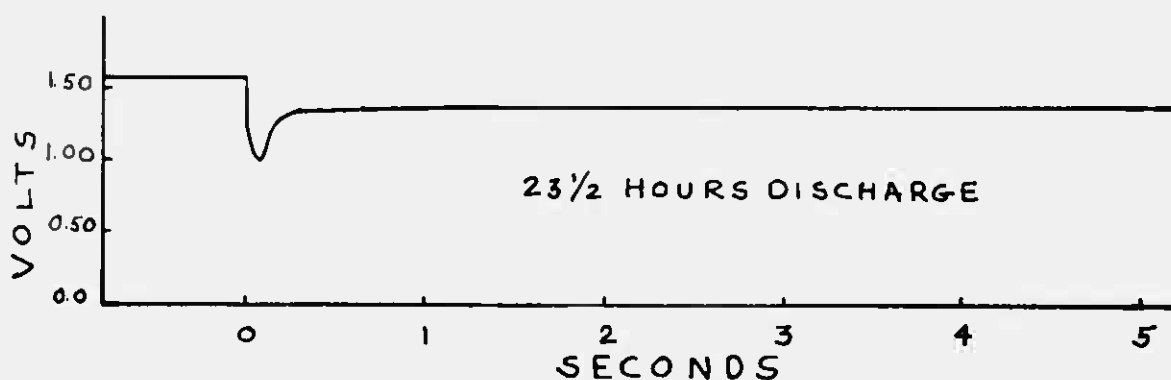
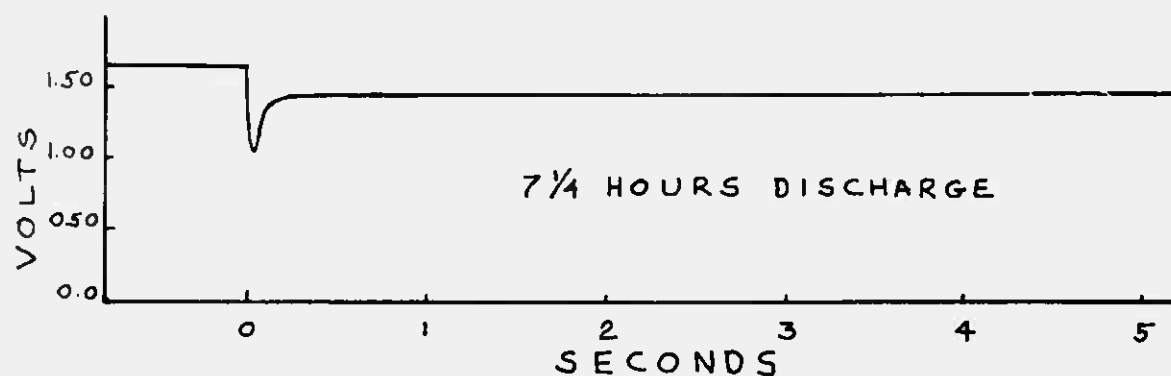
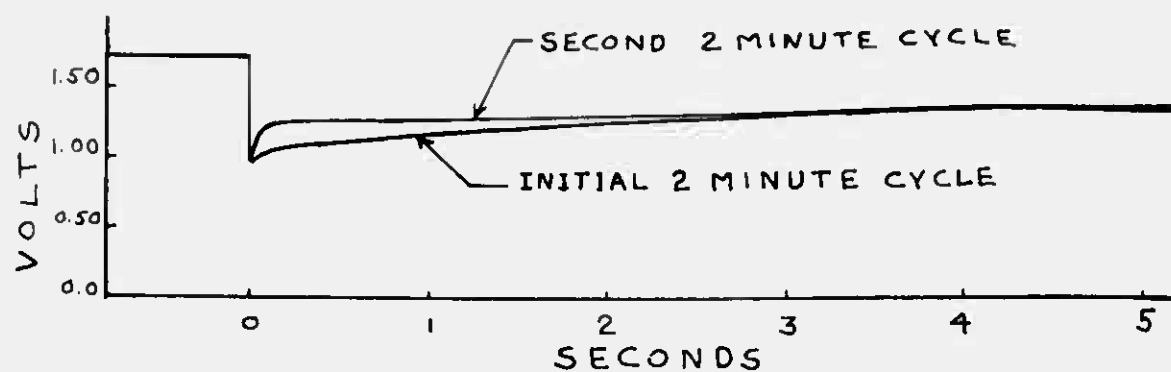


FIGURE 13. DELAYED ACTION CHARACTERISTICS OF $\text{Mg}/\text{Mg}(\text{ClO}_4)_2/\text{MnO}_2$ (TYPE M) AA SIZE CELLS AT 150 TO 8.93 OHM DRAIN

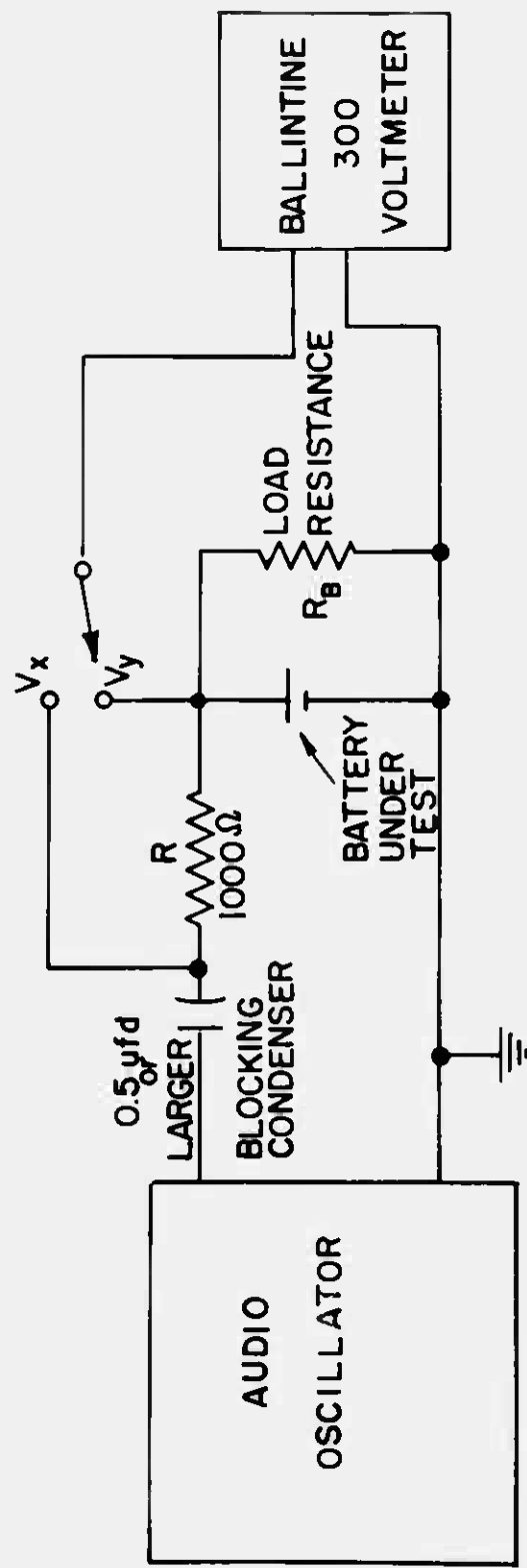


FIG. 14. EXPERIMENTAL APARATUS FOR MEASURING IMPEDANCE

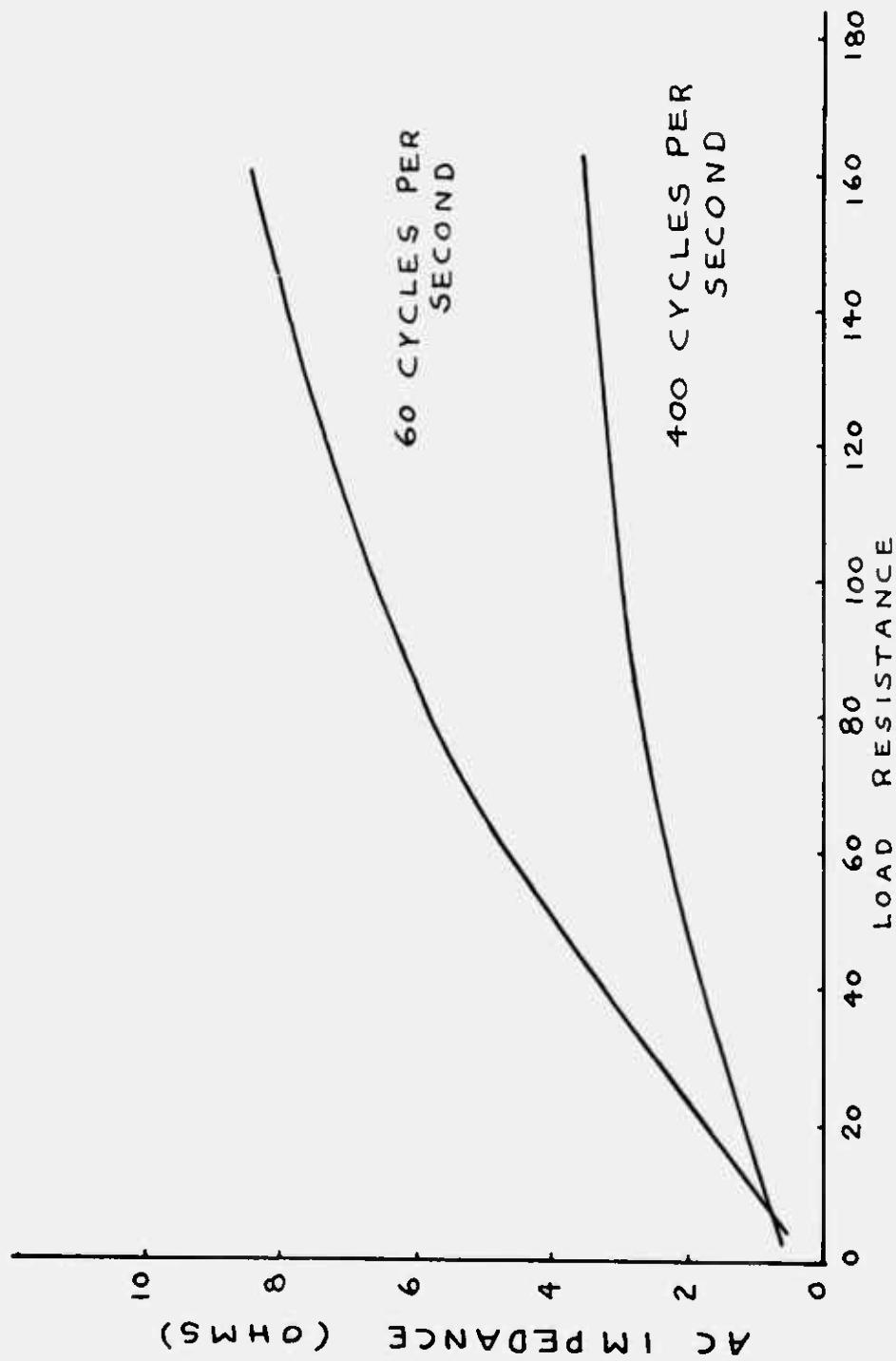


FIGURE 15. AC IMPEDANCE VS LOAD RESISTANCE OF AA SIZE

$\text{Mg} / \text{Mg}(\text{ClO}_4)_2 / \text{MnO}_2$ (TYPE M) CELLS DISCHARGED

CONTINUOUSLY THROUGH VARIOUS RESISTANCES

AT $70 \pm 2^\circ\text{F}$ AND $50 \pm 5\% \text{ RH}$

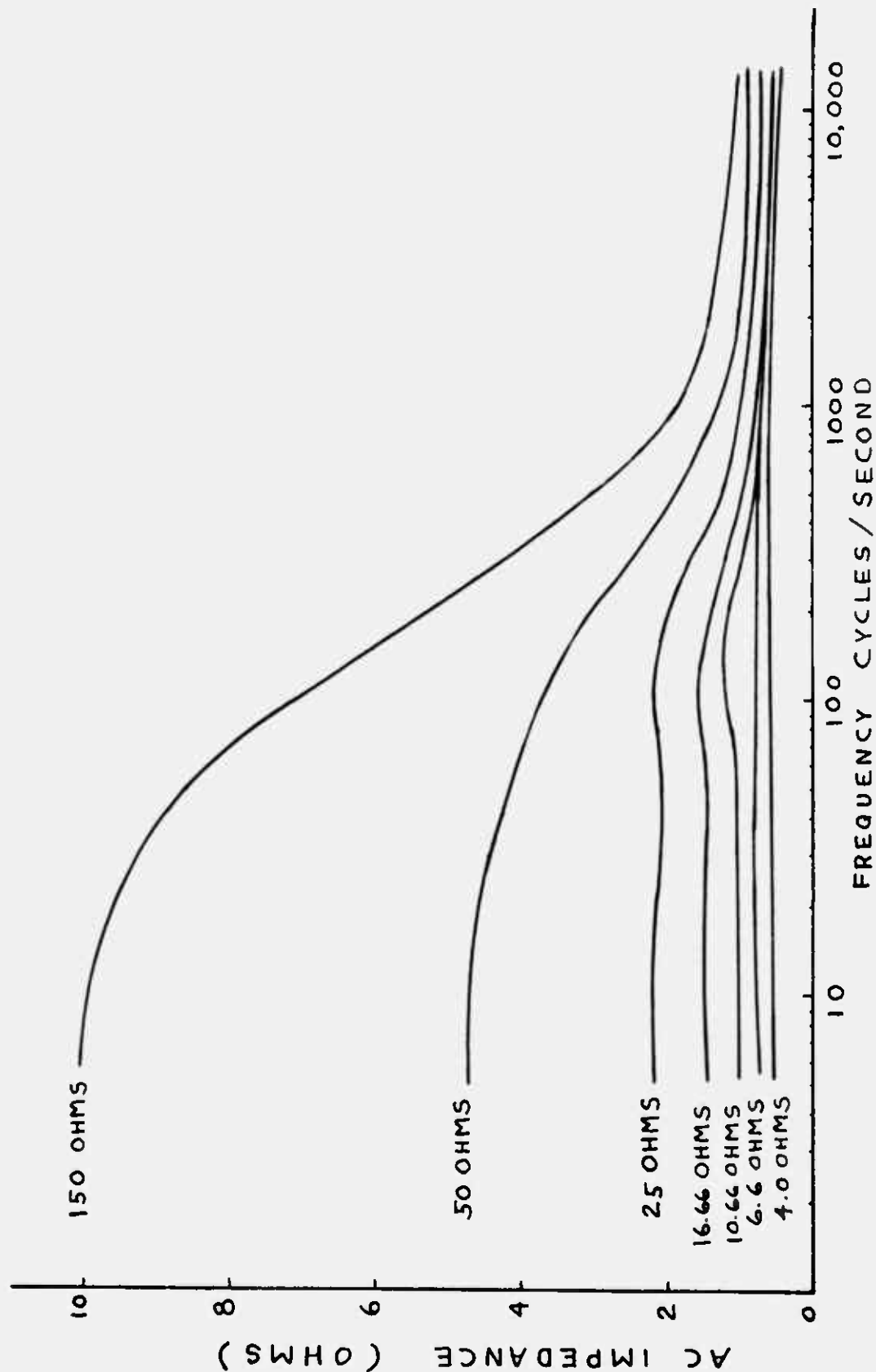


FIGURE 16. AC IMPEDANCE VS FREQUENCY OF AA SIZE $Mg/Mg(ClO_4)_2/MnO_2$
 (TYPE M) CELLS DISCHARGED CONTINUOUSLY THROUGH
 VARIOUS RESISTANCES AT $70 \pm 2^\circ F$ AND 50% RH

LOT	TYPE MnO ₂	DISCHARGE RESISTANCE (ohms)	INITIAL (Hours) (Minutes)		PER CENT CAPACITY RETENTION			
					3 MOS.	6 MOS.	9 MOS.	1 YEAR
A) 70 ± 2°F and 50 ± 5% R.H.								
29	M	16-2/3 166-2/3	13 166-1/2	22	98.5 103.0	101.0 98.5	93.6 93.7	96.7
30	WB-Pl	16-2/3 166-2/3	12 157		100.0 102.0	96.6 93.6	101.3 109.0	88.2
33	Trona C-8	16-2/3 166-2/3	10 144	45	95.4 112.0	81.5 113.0	88.4	
87*	M	16-2/3 166-2/3	14 175	37	95.8 104.0	91.7 111.0		
92*	WB-Pl	16-2/3 166-2/3	13 209	17	91.7 111.0	90.3 86.2		
B) 113 ± 2°F and 95% R.H.								
90 *	M	16-2/3 166-2/3	14 198	2	96.3 113.0	97.3 104.0	92.7 86.3	86.5
94 *	WB-Pl	16-2/3 166-2/3	12 209	55	94.8 112.0	94.1 86.2	89.2 76.0	88.3

* Tests are continuing.

TABLE 1
SHELF LIFE DATA FOR $Mg/Mg(ClO_4)_2/MnO_2$ CELLS WITH VARIOUS
TYPES OF MnO_2 STORED AT 70° AND 113°F

<u>CuO TO CARBON RATIO</u>	<u>WET MIX COMPOSITION</u>	<u>CATHODE PLATES PER CELL</u>	<u>THEORETICAL CATHODE CAPACITY PER CELL (Ampere-Minutes)</u>	<u>ANODE THICKNESS (INCHES) PURE Mg</u>	<u>DISCHARGE TIME TO 20 PER CENT VOLTAGE DROP (Minutes)</u>	<u>CATHODE EFFICIENCY (%)</u>
4 to 1 Shawinigan	42.8% CuO 10.7% Carbon 45.7% H ₂ O 0.7% HV CMC 4.9g mix/plate	4	340	.014	13	77
3 to 1 Shawinigan	33.3% CuO 11.1% Carbon 54.8% H ₂ O 0.83% HV CMC 4.45 g mix/plate	5	300	.010	13.2	88
2 to 1 Shawinigan	28.6% CuO 14.3% Carbon 56.2% H ₂ O 0.86% HV CMC 4.45 g mix/plate	6	308	.010	16	104
3 to 1 Columbian	27.6% CuC 9.2% Carbon 62.6% H ₂ O 0.48% HV CMC 4.45 g mix/plate	6	298	.010	14.9	100

TABLE 2

Mg/Mg(ClO₄)₂/CuO RESERVE CELLS WITH VARIOUS CARBON RATIOS

DISCHARGED ON A CONSTANT CURRENT OF 20 AMPERES

DISCHARGE RESISTANCE (ohms)	TIME OF SERVICE TO 0.9 V. (Hours)(Minutes)		AVERAGE VOLTAGE	WATT-HOURS PER POUND	WATT-HOURS PER INCH ³
4	1	35	1.32	26.8	1.64
6.6	3	5	1.36	33.7	2.07
10.66	5	25	1.39	39.6	2.42
16.66	10	15	1.40	46.9	2.88
25	17	15	1.445	55.8	3.43
50	35		1.46	58.0	3.50
150	123-1/2		1.53	75.0	4.58

TABLE 3

INITIAL CAPACITY DATA FOR AA SIZE $\text{Mg}/\text{Mg}(\text{ClO}_4)_2/\text{MnO}_2$ (TYPE M) CELLS DISCHARGED CONTINUOUSLY THROUGH
VARIOUS RESISTANCES AT $70 \pm 2^\circ\text{F}$ AND 50 PER CENT R.H.